

The Window of Opportunity: Why Today We Can (and Must) Build a Permanent Lunar Base

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Abstract

This paper identifies and analyzes the historic coincidence of three events that have never occurred together before: a new space race focused on the Moon, the emergence of giant reusable rockets, and the technological maturity accumulated over decades. Together, these three factors open a "window of opportunity" to establish a permanent human presence on the Moon. However, current architectures (Artemis, ILRS) remain anchored in the paradigm of isolated missions and heroic landers, inherited from the Apollo Program. This paper argues that such an approach is inadequate for the goal of "staying." The proposed alternative is a bidirectional logistics network between Earth and the Moon, moving mass, people, and resources continuously. Contrary to common belief, all the technologies needed to build such a network already exist and are mature. The only requirement is to change the mental framework: from the epic mission to persistent infrastructure.

Keywords: window of opportunity, permanent lunar base, bidirectional logistics network, reusable rockets, technological maturity, space race, lunar infrastructure.

Introduction

We are living in a truly extraordinary moment for anyone who follows—even from a distance—the development of spaceflight. A special, unrepeatable moment. Because today, a historic "window of opportunity" exists, a real inflection point. And like any window, it is open... but it can also close.

What does it consist of?

The temporal coincidence of three events:

- A new "space race" focused on the Moon.
- The deployment of giant rockets, such as the Falcon Heavy, the future NG 9x4, and Starship.
- The level of maturity achieved by space technologies, especially those that have been in use for decades.

Let us briefly analyze these events.

1. The New "Space Race" Focused on the Moon

NASA has reshaped its schedule to establish a presence on the lunar surface before the end of the decade, prioritizing the construction of a physical base over the Gateway orbital station [1].

The Artemis Accords provide an international framework of principles—not legally binding, but politically powerful—designed to guide civil exploration and the peaceful use of the Moon, Mars, and other celestial bodies.

On the other side, China and Russia signed a state agreement to cooperate on the construction of the ILRS, covering planning, design, development, implementation, and operation [4].

The ILRS is a joint Chinese-Russian lunar base, conceived as a scientific complex on the surface and/or in lunar orbit, with autonomous long-term operation capability. This project, led by the China National Space Administration (CNSA) and Roscosmos, aims to build an automated and eventually crewed base near the lunar south pole.

I will not dwell on this point. I believe the concept of a "space race" is clear enough. However, it is worth highlighting some differences from the one we knew in the 1960s.

Feature	Space Race (1955-1975)	New Space Race (Current)
Main Contenders	USA vs. USSR	USA vs. China (with Russia, India, and other actors)
Main Objective	Get there first: demonstrate ideological and military superiority through isolated milestones (Sputnik, Apollo 11).	Stay: establish a permanent presence, exploit lunar resources (water ice), and create a lunar economy.
Funding	Exclusively state-funded (NASA/Soviet Program) with massive defense budgets.	Hybrid model: public-private partnerships. Companies like SpaceX and Blue Origin are key players.
Technology	Development of ballistic missiles and expendable hardware.	Reusable rockets, commercial space stations, and AI applied to navigation.
Motivation	Global propaganda and symbolic impact.	Geopolitics of the lunar South Pole for strategic resources and control of cislunar space.

It is not our objective to delve into political or geostrategic issues beyond the scope of this paper. We will focus on highlighting that this is a key element of the window of opportunity because it changes Space Agencies' priorities and has the positive, unannounced but predictable effect of unlocking state funds for related programs.

2. The Deployment of Giant Rockets: Falcon Heavy, Future NG 9x4, and Starship

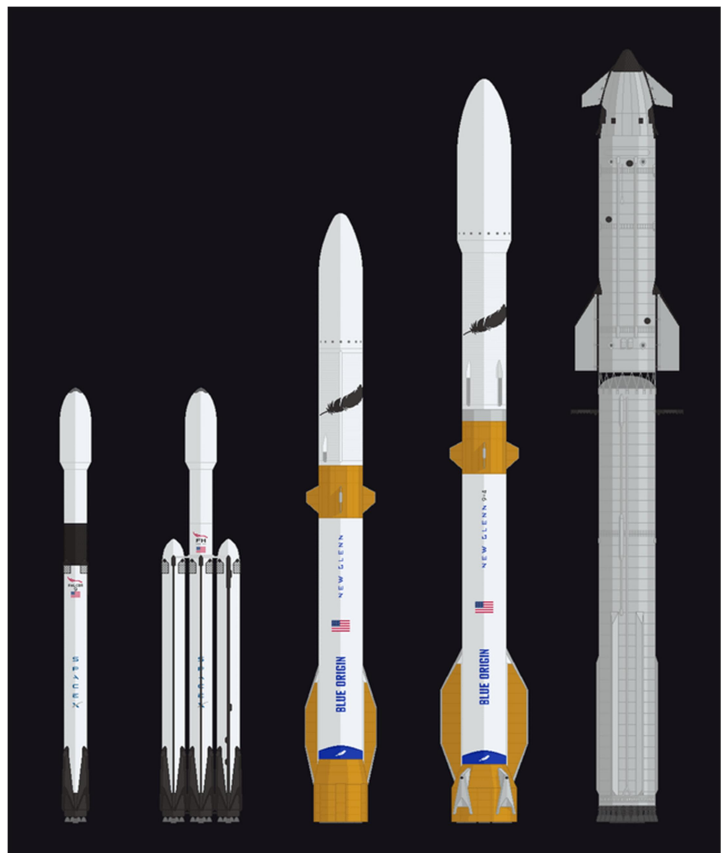
The arrival of SpaceX and other "NewSpace" companies, such as Blue Origin (with its New Glenn or NG rocket), has completely transformed the aerospace landscape, moving from a state monopoly model to a competitive, high-speed market economy [2].

The key has been rocket reusability. Before SpaceX, rockets were expendable, making each mission extremely costly.

- **Price reduction:** SpaceX has reduced the cost of putting cargo into orbit from about 15,000\$/kg *to less than* 1,000\$/kg with the Falcon 9.
- **New Standard (NG):** Blue Origin has followed this path with New Glenn, whose first booster flew successfully in April 2026 and is designed to be reused at least 25 times [5].

The technological evolution led by SpaceX and Blue Origin has redefined the concept of "heavy lift." As of May 2026, the industry has moved from celebrating the Falcon Heavy's 63 tons to projecting capabilities exceeding 100 and 200 tons with Starship.

Without these advances—if we were still relying on rockets with a payload capacity to LEO of no more than 25 tons—this article, and any other focused on establishing lunar bases and a human presence on the Moon, would simply have no practical meaning. It would be impossible to even think about it. The same can be said about the reduction in access costs to low Earth orbit. The costs would be absolutely unaffordable.



That is why this is a fundamental part of the window of opportunity.

3. The Level of Maturity Achieved by Space Technologies

I am not talking about future developments. Not even technologies that are "on the cusp" of being implemented. I am not talking about inventing new types of engines, nuclear fission reactors, how to avoid boil-off, or how to make an inflatable shield for aerobraking on Mars. I am talking about technologies that have been in use for decades and, precisely for that reason, have reached an admirable level of maturity and reliability [3]. I will name a few:

GNC (Guidance, Navigation, and Control)

- **Before:** The Apollo mission computers had less power than a current pocket calculator. Calculations were slow, and trajectory corrections were manual or widely spaced.
- **Now:** Modern convex optimization algorithms allow a rocket to calculate its landing trajectory thousands of times per second. This is what allows a Falcon 9 to land vertically on a moving barge, something physically impossible with 1990s computing.

Solar Photovoltaic Panels

- **Before:** Their efficiency was low (approx. 8-10%), and deployment was a critical point of mechanical failure.
- **Now:** Computer-aided design (CAD/CAE) and material simulations have enabled the creation of triple-junction cells with efficiencies exceeding 30%. Furthermore, ultra-precise solar tracking algorithms maximize energy capture even in low-light conditions (such as missions to Jupiter) [6].

Automated Rendezvous and Docking

- **Before:** It relied on analog radars that sometimes failed due to interference or proximity.
- **Now:** The current system (like the NASA Docking System or SpaceX's) uses LiDAR and computer vision. Computers compare the real image with a 3D model in milliseconds, allowing "soft" and autonomous docking with millimeter precision, without human intervention [7].

Hypergolic Engines: Reliability and Reusability

- **Now:**
 - **Generative Design:** Combustion chambers have been redesigned using algorithms that optimize cooling, allowing modern hypergolic engines to withstand hundreds of ignitions without degrading.

- **Diagnostic Sensors:** They now include Prognostic Health Management (PHM) systems that detect micro-cracks before the engine fails, enabling true reusability in orbital service vehicles [8].

Construction of Massive Structures

- **Now:**
 - **Digital Twins:** Before launching a structure, every thermal and mechanical stress is simulated on an identical digital model.
 - **Additive Manufacturing (3D Printing):** As of May 2026, companies like Relativity Space and Blue Origin are printing complete sections of rockets. This eliminates thousands of rivets and welds, creating much lighter, stronger structures that are easier to mass-produce (such as the New Glenn body) [9].

Transfer of Hypergolic Propellants

- **Before (1970s-80s):** Russian Progress ships perfected the transfer of hydrazine and nitrogen tetroxide to the Salyut station. This used external piping systems and mechanical couplings requiring very complex manual pressurization.
- **Now:** The process is managed by intelligent Flow Control Valves (FCVs). Ultrasonic flow and pressure sensors monitor the transfer in milliseconds to detect the formation of bubbles or pressure drops that could cause an explosion due to "water hammer" in the pipes.

Automation of Fluid Coupling

- **"Zero-Leak" Systems:** Thanks to computer-aided design (CAD) and advanced materials, current connectors ensure that not a single drop of propellant escapes into space during disconnection. This is vital, as residual hydrazine could corrode the spacecraft's sensors or damage astronauts' suits.
- **Robotics:** In missions like OSAM-1 (On-orbit Servicing, Assembly, and Manufacturing), robotic arms guided by computer vision are used to insert transfer nozzles into satellites that were not originally designed to be refueled [10].

Microgravity Management (Ullage Control)

- **Classical Techniques:** Bladders or elastic rubber diaphragms were used to "push" the fuel.
- **Now:** Using Computational Fluid Dynamics (CFD) simulations, Propellant Management Devices (PMDs) have been developed. These are fixed internal structures that use the liquid's surface tension to guide it to the outlet. Onboard software calculates exactly how much "thrust" or acceleration the spacecraft must provide (ullage burn) to settle the liquid at the bottom of the tank before initiating the transfer [11].

The Use of Miniature Nuclear Reactors

It is true that this point does not have years of operational experience, but not due to any physical or technological problem. They were under development in the 1960s, and their lack of implementation stemmed from reasons I will not go into because we all know them.

- **The Russian-Chinese Project: "Selena" Reactor:** Russia and China have signed a formal agreement to install an automated nuclear power plant on the lunar surface between 2033 and 2035. The prototype, called "Selena" (being developed by Russia's Kurchatov Institute), is initially planned as a 5 kW unit based on direct energy conversion technology. This reactor will power the ILRS and provide energy to "jumping robots" and intelligent mini-rovers that will operate autonomously [12].
- **US Micro-reactors: Fission Surface Power (FSP):** NASA, under a renewed partnership with the Department of Energy signed in January 2026, seeks to lead this field with 10-kilowatt class reactors. The goal is to deploy the first surface reactor by 2030. Key companies like Lockheed Martin, Westinghouse, and IX (Intuitive Machines and X-Energy) are already developing robust designs weighing less than 3,500 kg to facilitate transport on commercial landers. The Kilopower technology, based on the successful KRUSTY experiment, uses a uranium rod and Stirling engines to convert heat into electricity [13].
- **The Rolls-Royce Micro-reactor (United Kingdom):** The UK has also entered the race with a modular micro-reactor model designed to be as small as a car, intended to provide power to inhabited bases and life support systems for at least 10 years without human intervention [14].

These technologies are what open the window of opportunity. Not solving the boil-off problem, not creating cryogenic landers, not implementing nuclear engines. We do not need new engines. We do not need warp drives. We already have the engines we need.

4. Where Does This Window of Opportunity Invite Us?

To establish ourselves as a multiplanetary civilization, starting with the construction of true Permanent Lunar Bases. I am not talking about an isolated outpost, visited by professional astronauts once in a while. I am not even talking about something comparable to an Antarctic base, which, by the way, is still very distant on current space calendars.

I am talking about in-situ production, factories on the Moon, hydroponics, hotels, workshops, laboratories. I am talking about hundreds of people living and working there: technicians, operators, doctors, scientists, cooks, farmers, tourists. Not just astronauts. And yes, it requires time, investment, and effort. But it is not a fantasy. It is something that could become a reality in surprisingly short timeframes with an investment perfectly affordable by states and private companies.

What is at stake is enormous:

- Opening space to the real economy, to business, to private initiative.

- Establishing the standards and norms that will govern cislunar space.
- Securing priority access to strategic resources and positions.
- Having the gateway open to Mars and beyond.

Whoever gets there first, sets the rules.

5. The Natural Reaction: Disbelief

I perfectly understand those who, upon reaching this point, feel incredulity or distrust. It is a mature, reasonable reaction. The preceding paragraphs may sound like a beautiful wish list, an exercise in imagination with no real substance.

But it is not so.

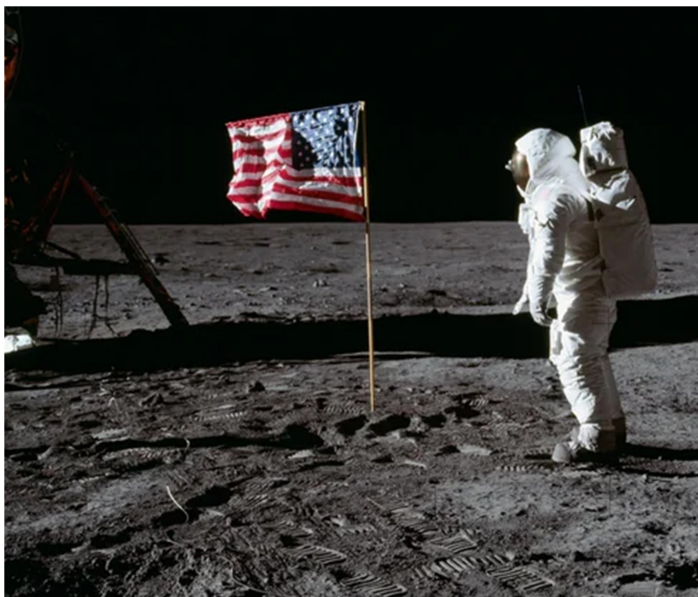
We have everything we need to make it a reality. Not in the distant future, but now. There are only two conditions:

1. Seize the window of opportunity.
2. Focus the problem correctly.

And today, unfortunately, we are not focusing it correctly.

Why Do I Say We Are Not Focusing Correctly?

Because we are still dragging, unconsciously, the conceptual aftermath of the Apollo Program. A program as successful as few—no one doubts it—but whose influence, precisely because of its greatness, conditions us to look at the current problem with a mental framework that no longer applies.



Apollo was an unrepeatable feat. We went to plant a flag, pick up some rocks, and come home before someone got killed along the way. And we did it. And we were lucky. And it was good to stop going: it was too precarious, too dangerous, too expensive.

My admiration for the engineers, scientists, and workers of Apollo is absolute. And whatever I could say here about the astronauts would never do them justice.

But today, the challenge is different. And our technology, sixty years later, is also different.

Today, we are not going to plant a flag and return. Today, we are going to stay.

It is a different thing. It is a different problem. And it must be thought about differently.

Yet, we remain trapped in the same logic:

- Isolated missions
- Sequential
- Self-sufficient
- Each with its own lander, its own profile, its own tragic end

We continue to imagine a giant rocket carrying a state-of-the-art cryogenic lander that goes up and down the steep mountains of delta-v to deliver a payload, only to then die of success, useless, abandoned on a desolate lunar plain.

Is that really an efficient way to approach the problem? Is that the architecture that will allow us to establish ourselves permanently on the Moon? I think not.

And I am not questioning the capability, perseverance, or intelligence of the wonderful scientists, engineers, and managers developing that vision. No. I am only saying that they are focusing the problem by looking in the wrong direction. If we really want to stay on the Moon, we do not need a sequence of successful missions.

What we need is **A BIDIRECTIONAL LOGISTICS NETWORK**.

Not a heroic lander. Not an epic mission. Not an isolated leap.

A network.

A network that moves mass, people, fuel, spare parts, water, oxygen, payloads, tools, food, experiments, manufactured products.

A network that works every day, not every two years. A network that allows going and returning, not just "going." A network that turns the Moon into an accessible place, not an exotic destination.

A bidirectional logistics network.

That is the heart of the problem. That is the blind spot of all current architecture. That is the step that no one is seeing. And today, we have everything we need to build it.

6. History Has Already Shown Us the Way

The Vikings reached America before Columbus [15], but they did not stay. Not because they lacked courage, but because they lacked logistics.

Columbus was not a solitary hero: he was the first node of a maritime network that Europe was already building [16]. And behind him came routes, ports, shipyards, commerce. It was not epic: it was infrastructure.

And much earlier, Rome did not dominate the world through its legions, but through its roads [17]. The Via Appia was not a symbol. It was a logistics infrastructure that moved:

- troops
- supplies
- information
- commerce
- people

Every day. For centuries.

Rome did not dominate the Mediterranean because it had better soldiers. It dominated because it had the best logistics network of the ancient world.

The lesson is always the same:

Civilizations are not born from heroic missions. They are born from logistics networks.

Today, we are in the "Viking" phase of the Moon: we arrive, do something extraordinary, and leave. If we want to move to the "Roman" phase, we need roads. We need a network.

A bidirectional logistics network between Earth and the Moon.

And most importantly: **today we have everything we need to build it.**

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